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ISOPARAMETRIC FINITE ELEMENTS A COMPUTER PROGRAM(U)
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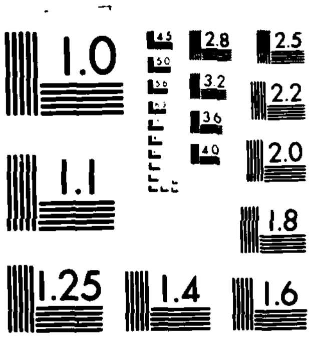

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Technical
Report
FPL 35

Plane Stress Analysis of Wood Members Using Isoparametric Finite Elements

A Computer Program

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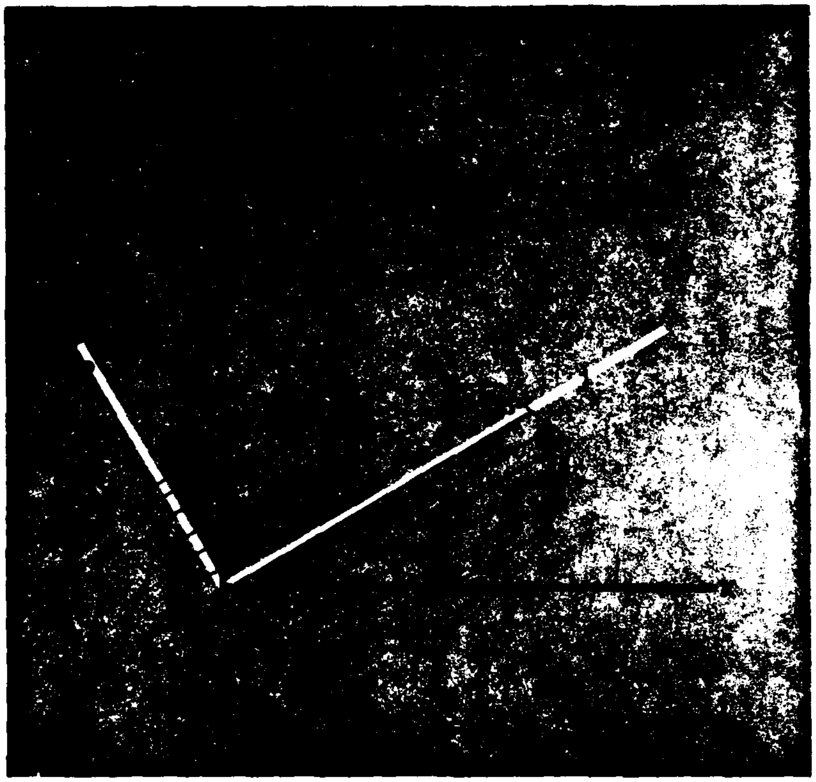

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Abstract

A finite element program is presented which computes displacements, strains, and stresses in wood members of arbitrary shape which are subjected to plane strain/stress-loading conditions. This report extends a program developed by R. L. Taylor in 1977, by adding both the cubic isoparametric finite element and the capability to analyze nonisotropic materials. The computer subroutines developed by the author are listed in this report, along with both the details for incorporating them into Taylor's program and the required user instructions.

Keywords: Finite element analysis, computer program, isoparametric elements, stress analysis, orthotropic materials, anisotropic materials, plane loading, design, cubic finite element, quadratic finite element.

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Plane Stress Analysis of Wood Members Using Isoparametric Finite Elements

A Computer Program

By
TERRY D. GERHARDT, Research Engineer

Introduction

The finite element (FE) computer program written by the author and presented in this report was developed as part of a cooperative research effort involving the National Wooden Pallet and Container Association (NWPCA), Virginia Polytechnic Institute and State University (VPI&SU), ~~and the USDA Forest Service.~~ This research is designed to establish rational engineering design procedures for wood pallets. The author's role in this endeavor is to determine the stiffness and strength of notched stringer members of pallets as functions of notch geometry, material properties, and loading conditions. As part of this effort, the author developed the FE program described in this paper to compute displacements and stresses in wood members of any geometrical shape which are under arbitrary plane stress or strain-loading conditions. This computer program is to be applied to the notched-stringer problem. Details of the program development, user instructions, and program listing are presented in this report. The program was verified by a comparison of FE predictions of displacements and strains in center-loaded, double-tapered wood beams with data available in the literature *(4)*.[2] This comparison is presented in another paper.

The developed subroutines are listed in the appendix, however no other support is offered.

Program Development

The decision to develop an FE program rather than purchase one of the many multipurpose programs available was based on several factors:

(1) The existence of subroutines in the literature to form the basis of a general-purpose FE program,

(2) The belief that a developed program could be more readily expanded for future research needs, and

(3) The desire to include the cubic isoparametric element in the program.

An FE computer program developed by Taylor *(6)* was used as a starting point. Taylor's program can input data for one-, two-, or three-dimensional structures. It is written in a modular form: Adding a new element requires writing a single subroutine. This flexibility is quite appealing to the researcher because the added element, whether a three-dimensional solid element or even a fluid or heat-transfer element, utilizes existing (and debugged) code for data input, matrix assembly, matrix inversion, etc. The program has a macro instruction language that allows a variable algorithm capability. Also, storage requirements are dynamically assigned for each problem and stored in a single array. In this manner, available computer memory is used efficiently for any type of problem. Finally, the following isoparametric plane elements are available: triangular, linear quadrilateral, quadratic serendipity and Lagrangian quadrilateral elements. A much more detailed description of the Taylor FE program is given in *(7)*.

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[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2] Italicized numbers in parentheses refer to literature cited at end of report.

[3] Gerhardt, T. D. On finite element modeling of tapered wood beams. In preparation. U.S. Dep. Agric. Forest Ser., For. Prod. Lab., Madison, Wis.

The program presented here adds to the Taylor program the capability to analyze nonisotropic materials and the cubic quadrilateral isoparametric plane element. The former addition makes analysis of wood- or composite-based structures possible by providing proper formulation for elements with orthotropic and anisotropic (wood with slope of grain) elastic properties. The cubic element can be easily collapsed to provide an accurate, fully compatible fracture mechanics element *(5)*. Although the cubic element is not included in commercially available FE programs, some researchers have used the cubic element to model certain regions in notch problems *(1,2)*.

User Instructions

To properly input data for an FE run, first review Taylor's *(6)* instructions in section 24.3, pages 690 to 695. These instructions need to be modified only minimally, with the exception of inputting the material property data. The following comments will consider both material property input and use of the cubic isoparametric element.

Inputting Material Property Data.

Four cards are now required for each material in the structure instead of the three required by Taylor *(6)*. The first two cards are identical to Taylor's. The first card indicates that material property data follows, and the second card inputs the material set number and the element type (IEL). IEL should be input as 1 for any of the plane stress/strain elements. Card 3 is in a 4I5,F10.0 format as follows:

Columns	*Variable*
1-5	MATYPE
6-10	I
11-15	L
16-20	K
21-30	ANGLE

MATYPE is the material-type variable and has the following values:

1 for isotropic materials.
2 for materials orthotropic in the global x-y plane.
3 for materials orthotropic in a local 1-2 plane (see fig. 1).
4 for anisotropic materials.

I is the plane loading variable and has the following values:

= 0 for plane strain loading.
≠ 0 for plane stress loading.

L is the order of Gaussian quadrature specified for stiffness matrix determination (L x L points/element).

K is the order of Gaussian quadrature specified for stress determination (K x K points/element).

ANGLE is the counterclockwise orientation of 1-2 local coordinates from global x-y coordinates (only used when MATYPE = 3); θ in figure 1.

The recommended order of Gaussian quadrature *(7)* is L = K = 3 for the cubic 12-node element, L = K = 2 for the quadratic 8-node element, and L = K = 1 for both the linear 4-node and triangular 3-node elements.

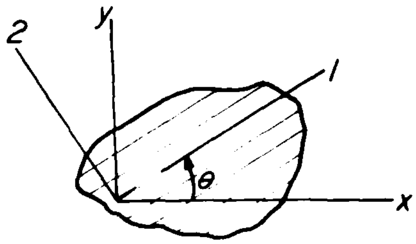

Figure 1.—Principal material axes. (M151918)

The fourth card is in an 8F10.0 format. The form of the fourth card depends on the value of MATYPE specified on the third card:

MATYPE = 1

Columns	*Variable*
1-10	D(4)
11-20	E
21-30	ν

MATYPE = 2

Columns	*Variable*
1-10	D(4)
11-20	E_x
21-30	ν_{xy}
31-40	E_y
41-50	G_{xy}
51-60*[4]	E_z*
61-70*	ν_{xz}*
71-80*	ν_{yz}*

MATYPE = 3

Columns	*Variable*
1-10	D(4)
11-20	E_1
21-30	ν_{12}
31-40	E_2
41-50	G_{12}
51-60*	E_3*
61-70*	ν_{13}*
71-80*	ν_{23}*

MATYPE = 4

Columns	*Variable*
1-10	D(4)
11-20	D_{11}
21-30	D_{12}
31-40	D_{13}
41-50	D_{22}
51-60	D_{23}
61-70	D_{33}

D(4) is material density—not needed for static analysis.
E is modulus of elasticity.
G is the shear modulus.
ν is Poisson's ratio.
D_{ij} are componets of the symmetric "Moduli of Elasticity" matrix for an anisotropic material. These components are defined in *(3)*.

---

[4] (*) indicates that these properties are only required for plane strain analysis (I = 0).

Specifiying 12-Node Cubic Isoparametric Element
The following steps are needed to specify the 12-node cubic isoparametric element:

(1) In the control card set NEN = 12.
(2) When inputting element data (ELEM) use the local node numbering sequence shown in figure 2.

The cubic element can be degenerated to either quadratic or linear displacement fields on any desired side by specifying IX = 0 for one or two of the side nodes. This capability is useful when the structure is to be modeled by more than one type of element. For example, it may be desirable to model regions in areas of suspected stress concentrations with cubic elements and the remainder of the structure with quadratic or linear elements.

Implementation of Program and Listing

The details required for incorporating the developed program into Taylor's program *(6)* are described in this section.

Deletions
Delete statements 31-36 in subroutine SHAP2 in *(6)*. This eliminates the nine-node Lagrangian element.

Additions
Add subroutines ELPROP, SHAP3, TRANSF, and BTREB in the appendix to the program in *(6)*.

Add the following 'Common' statement to subroutine PMESH in *(6)*:

```
COMMON / WRITE / PRT
```

Add the following 'Implicit' statement to all subroutines in *(6)* if double precision computations are desired:

```
IMPLICIT DOUBLE PRECISION (A-H,O-Z)
```

Substitutions
Substitute subroutine ELMT01 in the appendix for subroutine ELMT01 in *(6)*.

Substitute the two statements that follow for statement 18 in subroutine SHAPE in *(6)*:

```
120  IF(NEL.GT.4.AND.NEL.LE.8) CALL SHAP2
       (SS,TT,SHP,IX,NEL)

     IF(NEL.GT.8) CALL SHAP3(SS,TT,SHP,IX)
```

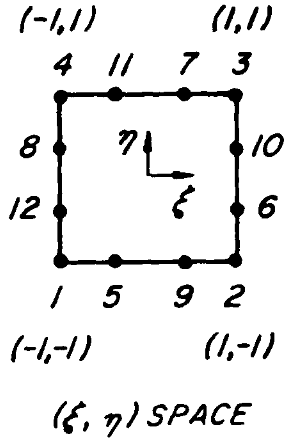

Figure 2—The cubic isoparametric element (local node numbering). (M151917)

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7. Zienkiewicz, O. C. The finite element method. 3rd ed. London: McGraw Hill; 1977. 787 p.

Appendix

The subroutines which follow were written in ASCII Fortran Level 9R1 (Sperry Univac Series 1100). This language allows IF-THEN-ELSE blocking statements. If the program is to be used with a version of Fortran which does not permit these statements, conventional IF statements must be substituted.

Subroutine ELPROP

```
      SUBROUTINE ELPROP(D)
C.... THIS SUBROUTINE DETERMINES MATRIX COEFFICIENTS OF [D] FOR
C.... ISOTROPIC OR ORTHOTROPIC MATERIALS UNDER PLANE STRESS/STRAIN
C.... LOADING CONDITIONS FROM THE APPROPRIATE MATERIAL CONSTANTS.
      IMPLICIT DOUBLE PRECISION (A-H.O-Z)
      LOGICAL PRT
      COMMON /CDATA/ O.HEAD(20).NUMNP.NUMEL.NUMMAT.NEN.NEQ.IPR
      COMMON/ELDATA/ DM.N.MA.MCT.IEL.NEL
      COMMON /WRITE/ PRT
      DIMENSION  D(1).WD(2).T(3.3).DXY(3.3)
      DATA  WD/4HRESS.4HRAIN
C....
      READ (5.1000) MATYPE.I.L.K.ANGLE
      READ (5.1001)  D(4).E1.RNU12.E2.G.E3.RNU13.RNU23
C.... DETERMINE WHETHER THE PROBLEM IS PLANE STRESS OR PLANE STRAIN.
      IF (I.NE.0)  I=1
      IF (I.EQ.0)  I=2
C.... STORE VALUE OF MATYPE (FOR USE IN SUBROUTINE ELMT01)
      D(1) = MATYPE
C.... STORE ORDERS OF GAUSIAN QUADRATURE TO BE USED IN STIFFNESS MATRIX
C.... AND STRESS EVALUATION (L AND K - FOR USE IN SUBROUTINE ELMT01)
      L = MIN0(3.MAX0(1.L))
      D(2) = L
      K = MIN0(3.MAX0(1.K))
      D(3) = K
      IF (PRT) WRITE(6.2000) WD(I).MATYPE
C....
C.... GO TO CORRECT ARRAY PROCESSOR
      GO TO (1.2.2.4).MATYPE
C....
C.... ISOTROPIC MATERIAL
C....
1     D(5) = E1*(1. + (1-I)*RNU12)/(1. + RNU12)/(1. - I*RNU12)
      D(6) = RNU12*D(5)/(1. + (1 - I)*RNU12)
      D(8) = E1/2./(1. + RNU12)
      D(7) = D(5)
      IF (PRT) WRITE(6.2101)  E1.RNU12
      GO TO 20
C....
C.... ORTHOTROPIC MATERIAL
C....
2     IF (MATYPE.EQ.2.AND.PRT)  WRITE (6,2202)
      IF (MATYPE.EQ.3.AND.PRT)  WRITE (6,2302)  ANGLE
      IF (PRT)  WRITE (6,2203)  E1.E2.RNU12,G
      D(8) = G
      RNU21 = RNU12*E2/E1
      IF (I.EQ.2) GO TO 10
C....    PLANE STRESS
         DUM = 1.0 - RNU12*RNU21
         D(5) = E1/DUM
         D(7) = E2/DUM
```

```
            D(3) = RNU12*D(7)
            GO TO 20
C....          PLANE STRAIN
10             RNU31 = RNU13*E3/E1
               RNU32 = RNU23*E3/E2
               DUM = 1. - RNU12*RNU21 - RNU13*RNU31 - RNU23*RNU32 -
     1          RNU21*RNU32*RNU13 - RNU12*RNU31*RNU23
               D(5) = E1*(1. - RNU23*RNU32)/DUM
               D(6) = E2*(RNU12 + RNU32*RNU13)/DUM
               D(7) = E2*(1. - RNU13*RNU31)/DUM
               IF (PRT)  WRITE (6.2204)  E3.RNU13.RNU23
30       IF (PRT) WRITE(6.2001)  D(4).L.L.K.K
         IF (MATYPE.EQ.3) GO TO 3
         RETURN
C....
C.... ORTHOTROPIC WITH RESPECT TO 1-2 COORDINATES
C....
C....      DETERMINE TRANSFORMATION MATRIX
3          CALL TRANSF (ANGLE.T)
C....      TRANSFORM PROPERTIES MATRIX TO GLOBAL (X.Y) COORDINATES.
           CALL BTREB (T.3.D(5).D(6).D(7).D(8).DXY)
           K=5
           DO 31 I=1.3
           DO 31 J=1.3
           D(K) = DXY(I.J)
           K = K + 1
31         CONTINUE
         RETURN
C....
C.... ANISOTROPIC MATERIAL
C....
4        IF (PRT)  WRITE (6.2402)  E1.RNU12.E2.G.E3.RNU13
         D(5) = E1
         D(6) = RNU12
         D(7) = E2
         D(8) = G
         D(9) = E3
         D(10) = RNU13
         GO TO 20
C.... FORMAT STATEMENTS
1000     FORMAT (4I5.F10.0)
1001     FORMAT (8F10.0)
2000     FORMAT(//.5X.8HPLANE ST.A4.23H LINEAR ELASTIC ELEMENT.10X.'MATYPE
        1= '.I2./)
2001     FORMAT(/20X.7HDENSITY.10X.E18.5.//20X.44HGAUSS PTS IN XI. ETA DIRE
        1CTIONS RESPECTIVELY./.30X.'(1). FOR STIFFNESS COMPUTATION'.5X.I1.
        2 '.'.I1./.30X.'(2). FOR STRESS COMPUTATION'.8X.I1.'.'.I1)
2101     FORMAT (10X.'ISOTROPIC MATERIAL'.//.15X.18HYOUNG'S MODULUS = . 4X.
        1E18.5./.15X.18HPOISSON'S RATIO = .10X.F8.5)
2202     FORMAT (10X.'ORTHOTROPIC MATERIAL. PRINCIPAL DIRECTIONS (1.2) COIN
        1CIDE WITH GLOBAL (X.Y) AXES RESPECTIVELY')
2203     FORMAT (1X.//.15X. 7HE1    = .  E18.5./.15X.7HE2    = .  E18.5./.15X
        1.7HNU12 = . 6X.F8.5./.15X.7HG12   = .E18.5)
2204     FORMAT (15X.7HE3    = . E18.5./.15X.7HNU13 = . 6X.F8.5./.15X.7HNU23
        1 = .6X.F8.5)
2302     FORMAT (10X.'ORTHOTROPIC MATERIAL. PRINCIPAL DIRECTION 1 ORIENTED
        1AT A CCW ANGLE OF '.F9.4.' DEGREES FROM THE GLOBAL X AXIS.')
2402     FORMAT  (10X.'ANISOTROPIC MATERIAL'.//.15X.'E(1.1) = '.E18.5./.15X
        1.'E(1.2) = '.E18.5/.15X.'E(1.3) = '.E18.5./.15X.'E(2.2) = '.E18.5.
        2/.15X.'E(2.3) = '.E18.5./.15X.'E(3.3) = '.E18.5)
         END
```

```
                                      ***  STATEMENT NUMBERS  ***
      1        30   *33
      2        39   *42
      3        64   *70
      4        79   *83
     10        47   *55
     20        38    53   *63    90
     31        74    75   *78
   1000        17   *92
   1001        11   *93
   2000        18   *94
   2001        43   *96
   2101        47   *99
   2202        42  *101
   2203        11  *103
   2204        [illegible]  *105
   2302        17  *107
   2402        37  *109
                                         ***  VARIABLES  ***
ANGLE         *13    47    70
RTPES          72
I               1    10   *14   *19   *23   *25   *33   *34   *35   *36   *45   *50
              *51   *52   *59   *60   *61    63    72   *76   *84   *85   *86   *87
              *88   *89
DM              8
IDUM          *43    50    51   *57    59    60    61
DXY            10    72    76
E1            *14    33    35    37    44    46    50    55    59    83    84
E2            *14    44    46    51    56    60    61    83    86
E3            *14    55    56    62    83    88
ELPROP          1
G             *14    44    45    83    87
HEAD            7
I             *13   *16   *17    26    33    34    47   *74    75    76
IEL             8
IFR             7
J             *75    76
K             *13   *24    25    63   *73    76   *77
L             *13   *22    23    63
MA              8
MATYPE        *13    19    26    29    42    43    64
MAX0           22    24
MCT             8
MIN0           22    24
N               8
NEL             8
NEN             7
NEQ             7
NUMEL           7
NUMMAT          7
NUMNP           7
O               7
PRT             6     9    26    37    42    43    44    62    63    83
RNU12         *14    33    34    35    37    44    46    49    52    57    60    83    85
RNU13         *14    55    57    60    61    62    83    89
RNU21         *46    49    57
RNU23         *14    56    57    59    62
RNU31         *55    57    61
RNU32         *56    57    59    60
T              10    70    72
TRANSF         70
WD             10   *11    26
```

Subroutine TRANSF

```
 1        SUBROUTINE TRANSF(BETA.T)
 2        IMPLICIT DOUBLE PRECISION (A-H.O-Z)
 3        DIMENSION T(3.3)
 4        DATA PI/3.141592653589793238D000/
 5 C.... THIS SUBROUTINE CONSTRUCTS THE PLANE TRANSFORMATION MATRIX [T]
 6 C.... FOR AN ANGLE OF BETA DEGREES. I.E. THE LOCAL 1-2 COORDINATES ARE
 7 C.... ORIENTATED BETA DEGREES COUNTER-CLOCKWISE OF THE GLOBAL
 8 C.... X-Y COORDINATES
 9        BETA = BETA*PI/180.
10        T(1.1) = DCOS(BETA)**2
11        T(1.2) = DSIN(BETA)**2
12        T(1.3) = DSIN(BETA)*DCOS(BETA)
13        T(2.1) = T(1.2)
14        T(2.2) = T(1.1)
15        T(3.2) =  2.0*T(1,3)
16        T(2.3) = -1.0*T(1.3)
17        T(3.1) =  2.0*T(2.3)
18        T(3,3) = T(1,1) - T(1,2)
19        RETURN
20        END
                                   ***  VARIABLES  ***
BETA           1     *9     10     11     12
DCOS          10     12
DSIN          11     12
PI            *4      9
T              1      3    *10    *11    *12    *13    *14    *15    *16    *17    *18
TRANSF         1
```

Subroutine BTREB

```
 1        SUBROUTINE BTREB (B.IBCOLS,E11.E12.E22,E33,PROD)
 2 C..... THIS SUBROUTINE COMPUTES THE MATRIX MULTIPLICATION BT*E*B = PROD
 3 C..... E IS A 3 BY 3 SYMMETRIC MATRIX WITH NON ZERO COMPONENTS E(1.1),
 4 C..... E(1.2).E(2.1).E(2.2).E(3.3).    B IS A 3 BY IBCOLS MATRIX.
 5 C..... PROD IS A SYMMETRIC MATRIX. ONLY THE UPPER HALF IS COMPUTED.
 6        IMPLICIT DOUBLE PRECISION (A-H,O-Z)
 7        DIMENSION  B(3.IBCOLS),PROD(IBCOLS.IBCOLS)
 8        DO 1 I=1.IBCOLS
 9        B1I = B(1.I)
10        B2I = B(2.I)
11        DUM1 = E11*B1I + E12*B2I
12        DUM2 = E12*B1I + E22*B2I
13        DUM3 = E33*B(3.I)
14        DO 1 J=I.IBCOLS
15 1      PROD(I.J) = B(1.J)*DUM1 + B(2.J)*DUM2 + B(3.J)*DUM3
16        RETURN
17        END
                                  ***  STATEMENT NUMBERS  ***

     1          8     14    *15
                                      ***  VARIABLES  ***
B               1      7      9     10     13     15
B1I            *9     11     12
B2I           *10     11     12
BTREB           1
DUM1          *11     15
DUM2          *12     15
DUM3          *13     15
E11             1     11
E12             1     11     12
E22             1     12
E33             1     13
I              *8      9     10     13     14     15
IBCOLS          1      7      8     14
J             *14     15
PROD            1      7    *15
```

Subroutine SHAP3

```
      SUBROUTINE SHAP3(XI,ETA,SHP,IX)
C.... THIS SUBROUTINE GIVES SHAPE FUNCTIONS AND NECESSARY
C.... DERIVATIVES FOR THE ISOPARAMETRIC CUBIC FOR SMT AS REQUIRED
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION IX(1),SHP(3,1)
C....
C.... SET VALUES FOR NEEDED CONSTANTS
      SQ = (1. - XI*XI)/2.
      TQ = (1. - ETA*ETA)/2.
      C0 = 27./16.
      ONETHD = 1./3.
      CXISQ = C0*SQ
      CETASQ = C0*TQ
      C1XI = XI - ONETHD
      C2XI = XI + ONETHD
      C1ETA = ETA - ONETHD
      C2ETA = ETA + ONETHD
      D1XI = CXISQ - C0*XI*C1XI
      D2XI = CXISQ - C0*XI*C2XI
      D1ETA = CETASQ - C0*ETA*C1ETA
      D2ETA = CETASQ - C0*ETA*C2ETA
      C1MXI = 1. - XI
      C1PXI = 1. + XI
      C1META = 1. - ETA
      C1PETA = 1. + ETA
C....
C.... ZERO SHP(J,II)
      DO 100 I = 5,12
      DO 100 J = 1,3
100   SHP(J,I) = 0.0
C.... IF MIDSIDE NODE II IS NOT SPECIFIED, I.E. IX(II) = 0,
C.... THEN SHP(J,II) ,J=1-3,WILL STILL EQUAL 0 AFTER THE
C.... FOLLOWING STATEMENTS
C.... THUS, THE CORNER NODES ON THIS EDGE WILL RETAIN ONLY
C.... QUADRATIC OR LINEAR TERMS
C....
C....
C.... COMPUTE SHAPE FUNCTIONS AND DERIVATIVES - SEE FIG.2 FOR NUMBERING
C....
      IF (IX(5).EQ.0.AND.IX(9).EQ.0) GO TO 101
         IF (IX(5).NE.0.AND.IX(9).NE.0) THEN
            SHP(1,5) = -C1META*D1XI
            SHP(2,5) = C1XI*CXISQ
            SHP(3,5) = -C1META*SHP(2,5)
            SHP(1,9) = C1META*D2XI
            SHP(2,9) = -C2XI*CXISQ
            SHP(3,9) = -C1META*SHP(2,9)
         ELSE
            SHP(1,5) = -XI*C1META
            SHP(2,5) = -SQ
            SHP(3,5) = SQ*C1META
         END IF
101   IF (IX(6).EQ.0.AND.IX(10).EQ.0) GO TO 102
         IF (IX(6).NE.0.AND.IX(10).NE.0) THEN
            SHP(1,6) = -C1ETA*CETASQ
            SHP(2,6) = -C1PXI*D1ETA
            SHP(3,6) = C1PXI*SHP(1,6)
            SHP(1,10) = C2ETA*CETASQ
            SHP(2,10) = C1PXI*D2ETA
            SHP(3,10) = C1PXI*SHP(1,10)
         ELSE
```

```
            SHP(1.6) = T2
            SHP(2.6) = -ETA*C1PXI
            SHP(3.6) = T2*C1PXI
         END IF
102   IF (IX(7).EQ.0.AND.IX(11).EQ.0) GO TO 103
         IF (IX(7).NE.0.AND.IX(11).NE.0) THEN
            SHP(1.7) = C1PETA*D2XI
            SHP(2.7) = C2XI*CXISQ
            SHP(3.7) = C1PETA*SHP(2.7)
            SHP(1.11) = -C1PETA*D1XI
            SHP(2.11) = -C1XI*CXISQ
            SHP(3.11) = C1PETA*SHP(2.11)
         ELSE
            SHP(1.7) = -XI*C1PETA
            SHP(2.7) = S2
            SHP(3.7) = S2*C1PETA
         END IF
103   IF (IX(8).EQ.0.AND.IX(12).EQ.0) GO TO 104
         IF (IX(8).NE.0.AND.IX(12).NE.0) THEN
            SHP(1.8) = -C2ETA*CETASQ
            SHP(2.8) = C1MXI*D2ETA
            SHP(3.8) = -C1MXI*SHP(1.8)
            SHP(1.12) = C1ETA*CETASQ
            SHP(2.12) = -C1MXI*D1ETA
            SHP(3.12) = -C1MXI*SHP(1.12)
         ELSE
            SHP(1.8) = -T2
            SHP(2.8) = -ETA*C1MXI
            SHP(3.8) = T2*C1MXI
         END IF
C....
C.... CORRECT CORNER NODES FOR PRESENCE OF MIDSIDE NODES
104   K = 8
      KK = 12
      DO 109 I = 1,4
      L = I + 4
      LL = I + 8
C.... ADJUST CORNER SHAPE FUNCTION FOR NODES ON THE CW SIDE
         IF(IX(KK).NE.0.AND.IX(K).NE.0)  THEN
            DO 111 J=1.3
111         SHP(J.I) = SHP(J.I) - ONETHD*(2.0*SHP(J.KK) + SHP(J.K))
         ELSE
            DO 121 J=1.3
121         SHP(J.I) = SHP(J.I) - 0.5*SHP(J.K)
         END IF
C.... ADJUST CORNER SHAPE FUNCTION FOR NODES ON THE CCW SIDE
         IF(IX(LL).NE.0.AND.IX(L).NE.0)  THEN
            DO 112 J=1.3
112         SHP(J.I) = SHP(J.I) - ONETHD*(2.0*SHP(J.L) + SHP(J.LL))
         ELSE
            DO 122 J=1.3
122         SHP(J.I) = SHP(J.I) - 0.5*SHP(J.L)
         END IF
      K = L
109   KK = LL
      RETURN
      END
```

```
                                        ***  STATEMENT NUMBERS  ***
   100          28    29   *30
   101          40   *53
   102          53   *66
   103          66   *79
   104          79   *94
   109          96  *116
   111         101  *102
   112         109  *110
   121         104  *105
   122         112  *113
                                            ***  VARIABLES  ***
 C0            *10    12    13    18    19    20    21
 C1ETA         *16    20    55    84
 C1MET         *24    42    44    45    47    49    51
 C1MXI         *22    82    83    85    86    89    90
 C1PETA        *25    68    70    71    73    75    77
 C1PXI         *23    56    57    59    60    63    64
 C1XI          *14    18    43    72
 C2ETA         *17    21    58    81
 C2XI          *15    19    46    69
 CETASQ        *13    20    21    55    58    81    84
 CXISQ         *12    18    19    43    46    69    72
 D1ETA         *20    56    85
 D1XI          *18    42    71
 D2ETA         *21    59    82
 D2XI          *19    45    68
 ETA             1     9    16    17    20    21    24    25    63    89
 I             *28    30   *96    97    98   102   105   110   113
 IX              1     5    40    41    53    54    66    67    79    80   100   108
 J             *29    30  *101   102  *104   105  *109   110  *112   113
 K             *34   100   102   105  *115
 KK            *95   100   102  *116
 L             *97   108   110   113   115
 LL            *98   108   110   116
 ONETHD        *11    14    15    16    17   102   110
 S2             *9    12    50    51    76    77
 SHAP3           1
 SHP             1     5   *30   *42   *43   *44   *45   *46   *47   *49   *50   *51
               *55   *56   *57   *58   *59   *60   *62   *63   *64   *68   *69   *70
               *71   *72   *73   *75   *76   *77   *81   *82   *83   *84   *85   *86
               *88   *89   *90  *102  *105  *110  *113
 T2             *9    13    62    64    88    90
 XI              1     8    14    15    18    19    22    23    49    75
```

Subroutine ELMT01

```
      SUBROUTINE ELMT01(D,UL,XL,IX,TL,S,P,NDF,NDM,NST,ISW)
C
C.... PLANE STRESS/STRAIN ELASTIC LINEAR ELEMENT ROUTINE.
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON /CDATA/ O,HEAD(20),NUMNP,NUMEL,NUMMAT,NEN,NEQ,IPR
      COMMON /ELDATA/ DM,N,MA,MCT,IEL,NEL
      DIMENSION D(1),UL(NDF,1),XL(NDM,1),IX(1),TL(1),S(NST,1),P(1)
     1  ,SHP(3,12),XI(9),ETA(9),WT(9),SIG(6),EPS(3)
C....
C.... GO TO CORRECT ARRAY PROCESSOR.
      GO TO (1,2,3,4,5,4), ISW
C....
C.... INPUT MATERIAL PROPERTIES.
C....
1     CALL ELPROP(D)
      LINT = 0
      RETURN
2     RETURN
C....
C.... DETERMINE ELEMENT STIFFNESS MATRIX S(I,J)
C....
3     L = D(2)
      IF(L*L.NE.LINT) CALL PGAUSS(L,LINT,XI,ETA,WT)
      MATYPE = D(1)
C....    FOR EACH INTEGRATION POINT COMPUTE STIFFNESS CONTRIBUTION
         DO 320 L = 1,LINT
         CALL SHAPE(XI(L),ETA(L),XL,SHP,DETJAC,NDM,NEL,IX,.FALSE.)
         DV = DETJAC*WT(L)
         D11 = D(5)*DV
         D12 = D(6)*DV
         IF (MATYPE.LE.2) THEN
            D22 = D(7)*DV
            D33 = D(8)*DV
         ELSE
            D13 = D(7)*DV
            D22 = D(8)*DV
            D23 = D(9)*DV
            D33 = D(10)*DV
         END IF
C....
C....    FOR EACH NODE J COMPUTE DB = D*B
C....
         DO 320 J = 1,NEL
         IF (MATYPE.LE.2) THEN
            DB11 = D11*SHP(1,J)
            DB12 = D12*SHP(2,J)
            DB21 = D12*SHP(1,J)
            DB22 = D22*SHP(2,J)
            DB31 = D33*SHP(2,J)
            DB32 = D33*SHP(1,J)
         ELSE
            DB11 = D11*SHP(1,J) + D13*SHP(2,J)
            DB12 = D12*SHP(2,J) + D13*SHP(1,J)
            DB21 = D12*SHP(1,J) + D23*SHP(2,J)
            DB22 = D22*SHP(2,J) + D23*SHP(1,J)
            DB31 = D33*SHP(2,J) + D13*SHP(1,J)
            DB32 = D33*SHP(1,J) + D23*SHP(2,J)
         END IF
C....
C....       FOR EACH NODE I COMPUTE S = BT*DB
```

```
C....
                   DO 320 I = 1.J
                   S(I+I-1.J+J-1)=S(I+I-1.J+J-1)+SHP(1.I)*DB11+SHP(2.I)*DB31
                   S(I+I-1.J+J)=S(I+I-1.J+J)+SHP(1.I)*DB12+SHP(2.I)*DB32
                   S(I+I.J+J-1)=S(I+I.J+J-1)+SHP(1.I)*DB21+SHP(2.I)*DB21
                   S(I+I.J+J)=S(I+I.J+J)+SHP(1.I)*DB32+SHP(2.I)*DB22
320                CONTINUE
C....
C.... COMPUTE LOWER TRIANGULAR PART BY SYMMETRY
C....
         NL = NEL + NEL
         DO 330 I =2.NL
         DO 330 J = 1.I
330      S(I.J) = S(J.I)
         RETURN
C....
C.... COMPUTE ELEMENT STRESSES. STRAINS. AND FORCES
C....
4        L = D(2)
         IF(ISW.EQ.4) L = D(3)
         IF(L*L.NE.LINT) CALL PGAUSS(L.LINT.XI.ETA.WT)
         MATYPE = D(1)
         DO 600 L = 1.LINT
C.... COMPUTE ELEMENT SHAPE FUNCTIONS
         CALL SHAPE(XI(L).ETA(L).XL.SHP.DETJAC.NDM.NEL.IX..FALSE.)
C.... COMPUTE STRAINS AND COORDINATES
         DO 410 I = 1.3
410      EPS(I) = 0.0
         XX = 0.0
         YY = 0.0
            DO 420 J = 1.NEL
            XX = XX + SHP(3.J)*XL(1.J)
            YY = YY + SHP(3.J)*XL(2.J)
            EPS(1) = EPS(1) + SHP(1.J)*UL(1.J)
            EPS(3) = EPS(3) + SHP(2.J)*UL(2.J)
420         EPS(2) = EPS(2) + SHP(1.J)*UL(2.J) + SHP(2.J)*UL(1.J)
C....       COMPUTE STRESSES
            IF (MATYPE.LE.2) THEN
               SIG(1) = D(5)*EPS(1) + D(6)*EPS(3)
               SIG(3) = D(6)*EPS(1) + D(7)*EPS(3)
               SIG(2) = D(8)*EPS(2)
            ELSE
               SIG(1) = D(5)*EPS(1) + D(6)*EPS(3) + D(7)*EPS(2)
               SIG(3) = D(6)*EPS(1) + D(8)*EPS(3) + D(9)*EPS(2)
               SIG(2) = D(7)*EPS(1) + D(9)*EPS(3) + D(10)*EPS(2)
            END IF
C.... GO TO STATEMENT 620 FOR COMPUTATION OF ELEMENT NODAL FORCES
         IF(ISW.EQ.6) GO TO 620
         CALL PSTRES(SIG.SIG(4).SIG(5).SIG(6))
C.... OUTPUT STRESSES AND STRAINS
         MCT = MCT - 2
         IF(MCT.GT.0) GO TO 430
         WRITE(6.2001) O.HEAD
         MCT = 50
430      WRITE(6.2002) N.MA.XX.YY.SIG.EPS
         WRITE (26.2010) N.XX.YY.EPS(1).EPS(3).EPS(2)
600      CONTINUE
         RETURN
C....
C.... COMPUTE INTERNAL FORCES
C....
620      DV = DETJAC*WT(L)
```

```
134          J1 = 1
135          DO 610 J = 1.NEL
136          P(J1) = P(J1) - (SHP(1.J)*SIG(1) + SHP(2.J)*SIG(2))*DV
137          P(J1+1) = P(J1+1) - (SHP(1.J)*SIG(2) + SHP(2.J)*SIG(3))*DV
128 610      J1 = J1 + NDF
129          GO TO 600
130 C....
131 C.... COMPUTE CONSISTENT MASS MATRIX - SEE TAYLOR'S ELMT01
132 C....
133 5        WRITE (6.990)
134 990      FORMAT (10X.'**** MASS MATRIX FORMULATION FOR THIS ELEMENT
135         1 'IS NOT AVAILABLE AT THIS TIME ****')
136          STOP
137 C.... FORMATS FOR INPUT-OUTPUT
138 2001     FORMAT(A1.20A4/5X.16HELEMENT STRESSES//.5X.30H  ELEMENT  MATERIAL
139         1    .7H1-COORD.6X.7H2-COORD.4X.9H11-STRESS.4X.9H12-STRESS.4X.
140         2  9H22-STRESS.5X.9H1-STRESS.5X.8H2-STRESS.3X.5HANGLE/50X.
141         3  9H11-STRAIN.4X.9H12-STRAIN.4X.9H22-STRAIN)
142 2002     FORMAT(2I10.3F13.4.5E13.4.F8.2/46X.3E13.4)
143 2010     FORMAT(I3.5D15.5)
144          END
                                   ***  STATEMENT NUMBERS  ***
      1        12   *16
      2        12   *19
      3        12   *23
      4        12   *80
      5        12  *133
    320        27    44    63   *68
    330        73    74   *75
    410        88   *89
    420        92   *97
    430       113  *116
    600        84  *118   129
    610       125  *128
    620       109  *123
    990       133  *134
   2001       114  *138
   2002       116  *142
   2010       117  *143
                                       ***  VARIABLES  ***
D               1     8    16    23    25    30    31    33    34    36    37    38
               39    80    81    83   100   101   102   104   105   106
D11           *30    46    53
D12           *31    47    48    54    55
D13           *36    53    54    57
D22           *33   *37    49    56
D23           *38    55    56    58
D33           *34   *39    50    51    57    58
DB11          *46   *53    64
DB12          *47   *54    65
DB21          *48   *55    66
DB22          *49   *56    67
DB31          *50   *57    64    66
DB32          *51   *58    65    67
DETJAC         28    29    86   123
DM              7
DV            *29    30    31    33    34    36    37    38    39  *123   126   127
ELMT01          1
ELPROP         16
EPS             8   *89   *95   *96   *97   100   101   102   104   105   106   116
              117
ETA             8    24    28    82    86
```

```
HEAD          8     114
I           *63      64      65      66      67     *68   [illegible] [illegible] [illegible]  89
[illegible]   [illegible]
[illegible]   6
[illegible]   1      1[illegible]  31     11[illegible]
[illegible]   1      [illegible]   [illegible]  [illegible]
[illegible] [illegible]  [illegible]  47  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
            [illegible]  [illegible]  54  65  [illegible]
            [illegible]  [illegible] *1[illegible]  126  1[illegible]
[illegible] *1[illegible]  1[illegible]  1[illegible]  *1[illegible]
[illegible] [illegible]  [illegible]  *[illegible]  38  [illegible]  [illegible]  [illegible]  *[illegible]  [illegible]  [illegible]
[illegible] [illegible]  [illegible]  [illegible]  82  [illegible]
[illegible]              1[illegible]
[illegible] [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
[illegible]             *1[illegible]  112  *115
[illegible]              [illegible]  1[illegible]
[illegible]              [illegible]  1[illegible]
[illegible]   [illegible]  [illegible]  38  [illegible]
[illegible]   [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  1[illegible]
[illegible]
[illegible]   [illegible]
[illegible]   [illegible]   73
[illegible]   1     [illegible]
[illegible]   [illegible]
[illegible]   [illegible]
[illegible]   [illegible]
[illegible]   [illegible]   [illegible]
[illegible]   [illegible]   [illegible]  *1[illegible]  [illegible]
[illegible]   11    [illegible]
[illegible]   1[illegible]
[illegible]   1      8     *64   [illegible]  [illegible]  *67    *75
SHAPE        1[illegible]   [illegible]
SHP           1     [illegible]   46   [illegible]   48    49    50    51    53    54    55    56
            [illegible]  [illegible]  [illegible]  [illegible]  66  [illegible]  [illegible]  93  94  95  96  97
            1[illegible]  127
[illegible]   5   *1[illegible]  *101  *102  *104  *105  *106   110   116   126   127
TL            1     [illegible]
[illegible]   1     [illegible]   95    96    97
[illegible]   [illegible]  [illegible]  39  [illegible]  123
[illegible]   [illegible]  [illegible]  38  82  [illegible]
[illegible]   1      2    [illegible]   86    93    94
[illegible]  *[illegible]  *97   116   117
[illegible]  *91    *94   115   117
```

1.5-16-4/83

Gerhardt, Terry D. **Plane stress analysis of wood members using isoparametric finite elements: A computer program.** USDA For. Serv. Gen. Tech. Rep. FPL 35. Madison, WI: For. Prod. Lab.; 1983. 16 p.

A finite element program is presented for stress analysis of wood members of arbitrary shape which are subjected to plane strain/stress-loading conditions. This program extends one which is available in the literature. User instructions and a listing of the developed subroutines are presented.

Keywords: Finite element analysis, computer program, isoparametric elements, stress analysis, orthotropic materials, anisotropic materials, plane loading, design, cubic finite element, quadratic finite element.

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